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PARAMETRIC OPTIMIZATION OF TIG WELDING TO DETERMINE WELDING STRENGTH OF S30430 STAINLESS STEEL

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ABSTRACT

Pulsed TIG welding is one of the most widely used welding processes in the metal manufacturing industry. In any fusion arc welding process, the weld bead geometry plays an important role in determining the welding strength and mechanical properties of the weld joint. The prediction of welding strength together with the shape of the weld bead was accomplished taking into account of TIG welding process parameters such as welding current, arc length, welding speed. Full factorial design of experiment methodology was followed while selecting control factor. This paper present optimization of the pulsed TIG welding process parameter using Taguchi Philosophy. For the establishment of the optimum combination of the process parameter and depending upon the functional requirement of the welded joint, the acceptable welded joint should have maximum penetration, minimum bead width, minimum HAZ etc. Therefore there exists an increasing demand to evaluate an optimum parameter setting. Based on Taguchi approach the present study has been aimed at integrating statistical techniques into the engineering process. An experiment was conducted using different welding condition and a mathematical model was constructed using the data collected from the experiment based on Taguchi L_{27} orthogonal array, with three different levels of the parameter. The process parameter having higher Signal to Noise ratio will give optimum parameter.

KEYWORDS: TIG Welding, Taguchi Philosophy & Minimum HAZ

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Original Article

INTRODUCTION

In today's scenario welding of thin sheets is being the challenging task in the field of Engineering. The major reason behind this is perfection, which is being the nominal factor considered during the joining process of sheets because, in such joining of the plate, two passes and three pass welding cannot be carried out in thin sheets below 4mm, as under welding results in predominant reduction in strength and over weld results from information of the hole. Hence, optimization of weld parameter plays a predominant role in joining of thin sheets. This research is to make the thin sheet welding easy and compatible by optimizing the process parameters. Welding is great significant operation in any manufacturing industry [1]. It is absolutely necessary to optimize different welding process parameters so that industry achieves reliable, productive and good quality product. Nowadays global manufacturing industries are more focused toward R&D. To investigate welding process parameter such as current, voltage, inert gas, pulsed on/off time, etc. TIG welding process is commonly used operation for joining of two materials with the application of heat. TIG is also known as Gas Tungsten Arc Welding (GTAW). Arc is maintained between a non-consumable electrode and work piece in a protective inert gas atmosphere [2]. The various studies are done to investigate the influence of welding process parameter on tensile

strength [3].

EXPERIMENTAL LAYOUT

In order to perform an experiment for data collection following sequence is followed. Selecting the base and filler material. Selecting pulsed TIG welding parameters. Finding the upper and lower limits of the identified process parameters. Select the appropriate orthogonal array. Conduction of the experiments as per the selected orthogonal array. Find the optimum condition.

Selecting Base Material and their Mechanical Properties

S30430 stainless steel sheets of dimension 100 × 150 × 3 mm are welded autogenously with a butt joint without edge preparation [4]. The chemical composition of the S30430 stainless steel sheet is given in Table 1. Mechanical Properties of S30430 Stainless steel are given in Table 2.

Table 1: Chemical Composition of Base Material (Wt %)

Ust Designation	% Cr	% Ni	% C	% Mn	% Si	% P	% S
S30430	18	8	0.03	2	0.75	0.045	0.03

Table 2: Mechanical Properties of S30430

Tensile Strength	Yield Strength	Hardness	Melting Point	Density
564TMPA	241TMPA	B80THBN	1400-1450T^{0}C	8Tg/cm^3

Identify the Pulsed Welding Process Parameter

From the literature survey [5-6] and previous work is done the most important process parameters which are having a greater influence on the weld bead geometry. They are welding speed, welding current, arc length.

Level of the Working Range

Numbers of experiment has been conducted by varying one of the process parameters and keeping the others constant). The working range of the process parameters is shown in Tables 3.

Table 3: Process Parameters Working Range

Factor/Process Parameter	Code	Level 1	Level 2	Level 3
Welding current (Amp)	A	55	75	95
Arc length (mm)	B	2	2.5	3
Welding speed (mm/min)	C	15	30	45

An Orthogonal Array is Selected

Process parameters selected for this experiment are three, and the level of each parameter is three. Taguchi orthogonal design of experiment uses a special set of predefined arrays called orthogonal arrays (OA) to design the plan of the experiment [7]. These standard arrays provide the way to full information on all three factors that affect the process performance [5-6]. For the present experimental work, three factors with their three levels are used for which the corresponding orthogonal array is L9 as shown in Table 4.

Table 4: Orthogonal Array TL_9 (Minitab18)

Experiment No.	Process Parameter		
	A	B	C
1	1	1	1
2	1	1	2
3	1	1	3
4	1	2	1
5	1	2	2
6	1	2	3
7	1	3	1
8	1	3	2
9	1	3	3
10	2	1	1
11	2	1	2
12	2	1	3
13	2	2	1
14	2	2	2
15	2	2	3
16	2	3	1
17	2	3	2
18	2	3	3
19	3	1	1
20	3	1	2
21	3	1	3
22	3	2	1
23	3	2	2
24	3	2	3
25	3	3	1
26	3	3	2
27	3	3	3

Taguchi Methodology

Taguchi's philosophy is an efficient tool for the design of high-quality manufacturing systems. Dr. Genichi Taguchi, a Japanese quality management consultant, has developed a method based on orthogonal array experiments, which provide a much-reduced variance for the experiment with the optimum setting of process control parameters. Thus the integration of design of experiments (DOE) with parametric optimization of the process is achieved with the Taguchi method. This will provide the desired results. The desired results refer to the acceptable quality parameters of the product. For welded joint, this will mean desired mechanical properties of the joint, which-in turn-depend on bead geometry. Again, control of the process parameters will lead to optimal bead. An orthogonal array (OA) provides a set of well balanced (minimum experimental runs) experiments and Taguchi's signal-to-noise ratios (S/N), which is logarithmic functions of desired output; serve as objective functions for optimization. This helps in data analysis and prediction of optimum results. The steps involved in the Taguchi method are as follows [8-13]

Signal to Noise Ratio

In order to evaluate optimal parameter settings, the Taguchi method uses a statistical measure of performance called signal-to-noise ratio. The S/N ratio developed by Dr. Taguchi is a performance measure to select control levels that best cope with noise. The S/N ratio takes both the mean and the variability into account. The S/N ratio is the ratio of the mean (signal) to the standard deviation (noise). The ratio depends on the quality characteristics of the product/process to be

optimized [14]. The standard S/N ratios generally used are as follows: nominal-is-best (NB), lower-the-better (LB), and higher-the-better (HB). In this paper, the characteristic values are selected by the bead width, reinforcement, depth of penetration and HAZ width, since a good result is obtained by the smaller bead width, reinforcement, HAZ width and deeper depth of penetration. Hence for bead width, reinforcement and HAZ width LB is preferred. For depth of penetration, the HB criterion has been selected. The S/N ratio for LB and HB can be calculated by [15]:

- **Larger the Better**

  S/N Ratio = $-10\log. 1/n\, [\sum_{i=0} 1/y_i^2]$

- **Smaller the Better**

  S/N Ratio = $-10\log.1/n\, [\sum_{i=0} y_i^2]$

- **Nominal the Best**

  S/N Ratio = $-10\log\, [\sum_{i=0} \bar{y}_i^{\,2}/s^2]$

  Where,

  n = Number of trials or measurement

  yi = measured value

  ȳ = mean of the measured value

  s = standard deviation

Conduction of Experiment

The design matrix has been selected based on Taguchi's orthogonal array design of L_{27} (9*3) consisting of twenty-sevensets of coded conditions [16] (Table 5). The parameters, which were kept invariant during experimentation, are listed in Table 5. Utilizing the experimental data of Table 5, the S/N ratios for each of the features have been calculated Table 6.

Table 5: Experimental Data of TIG Welding

SI. No.	Current (A)	Arc Length (mm)	Welding Speed (mm/s)	Bead Width (mm)	Depth of Penetration (mm)	Depth of HAZ (mm)	Width of HAZ (mm)
1	55	2	15	5.46	1.59	1.73	1.83
2	55	2	30	4.71	1.25	1.19	1.35
3	55	2	45	4.61	1.04	1.02	1.13
4	55	2.5	15	5.77	1.76	1.94	2.20
5	55	2.5	30	4.93	1.38	1.33	1.63
6	55	2.5	45	4.46	1.18	1.16	1.33
7	55	3	15	6.09	1.91	2.13	2.45
8	55	3	30	5.03	1.42	1.51	1.84
9	55	3	45	4.55	1.23	1.23	1.46
10	75	2	15	6.12	1.99	2.48	2.25
11	75	2	30	5.13	1.39	1.46	1.72
12	75	2	45	4.59	1.16	1.22	1.39
13	75	2.5	15	6.59	2.06	2.65	2.41

Table 5: Contd.,							
14	75	2.5	30	5.26	1.50	1.65	1.89
15	75	2.5	45	4.85	1.32	1.34	1.57
16	75	3	15	7.07	2.18	2.72	2.79
17	75	3	30	5.45	1.65	1.86	2.02
18	75	3	45	5.16	1.45	1.58	1.79
19	95	2	15	6.65	2.17	3.04	2.71
20	95	2	30	5.38	1.51	1.81	1.94
21	95	2	45	4.75	1.23	1.49	1.52
22	95	2.5	15	7.19	2.23	3.32	2.89
23	95	2.5	30	6.16	1.63	1.97	2.15
24	95	2.5	45	5.2	1.32	1.56	1.75
25	95	3	15	7.64	2.51	3.21	3.15
26	95	3	30	6.31	1.74	2.15	2.70
27	95	3	45	5.11	1.41	1.74	2.16

Table 6: Signal to Noise Ratio for All Process Parameter

SI. No.	Current (A)	Arc Length (mm)	Welding Speed (mm/s)	S/N Ratio Bead width (mm)	S/N Ratio Depth of Penetration (mm)	S/N Ratio Depth of HAZ (mm)	S/N Ratio Width of HAZ (mm)
1	55	2	15	13.7781	1.84841	1.75775	2.64814
2	55	2	30				
3	55	2	45				
4	55	2.5	15	13.9271	2.82298	2.80064	4.17061
5	55	2.5	30				
6	55	2.5	45				
7	55	3	15	14.1722	3.21472	3.56556	5.08126
8	55	3	30				
9	55	3	45				
10	75	2	15	14.2727	2.97210	3.61982	4.54642
11	75	2	30				
12	75	2	45				
13	75	2.5	15	14.6988	3.78819	4.49109	5.43727
14	75	2.5	30				
15	75	2.5	45				
16	75	3	15	15.1698	4.54547	5.60777	6.41024
17	75	3	30				
18	75	3	45				
19	95	2	15	14.7073	3.59213	5.40669	5.55595
20	95	2	30				
21	95	2	45				
22	95	2.5	15	15.5972	4.15899	5.96702	6.55874
23	95	2.5	30				
24	95	2.5	45				
25	95	3	15	15.7109	4.80603	6.68454	8.21704
26	95	3	30				
27	95	3	45				

The objective is to obtain the factor combination that would optimize S/N ratio, i.e. maximize S/N ratio (higher-the-better for penetration) or minimize S/N ratio (lower-the-better for bead width, depth & width of HAZ. By using the MiniTab15 statistical software we determine response table for the signal to noise ratio and for mean as given in Table 7, Table 8, Table 9, Table 10, Table 11, Table 12, Table 13, Table 14.

Table 7: Bead width Response Table for Mean

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	5.068	5.267	5.668
2	5.580	5.601	5.62
3	6.043	5.823	0.461
Delta	0.976	0557	0.207
Rank	1	2	3

Table 8: Bead Width Response Table for S/N Ratio

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	13.96	14.25	1485
2	14.71	14.74	4.64
3	15.34	15.02	14.53
Delta	1.38	0.76	0.32
Rank	1	2	3

Table 9: Depth of Penetration Response Table for Mean

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	1.1418	1.481	1.593
2	1.633	1.598	1.613
3	1.750	1.722	1.594
Delta	0.332	0.241	0.020
Rank	1	2	3

Table 10: Depth of penetration Response Table for S/N Ratio

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	2.629	2.804	3.518
2	3.769	3.590	3.534
3	4.186	4.189	3.532
Delta	1.557	1.385	0.016
Rank	1	2	3

Table 11: The Depth of HAZ Response Table for Mean

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	1.471	1.716	1.883
2	1.884	1.880	1.854
3	2.254	2.014	1.872
Delta	0783	0.299	0.029
Rank	1	2	3

Table 12: The Depth of HAZ Response Table for S/N Ratio

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	2.708	3.595	4.444
2	4.573	4.420	4.368
3	6.019	5.285	.48
Delta	3.311	1.691	0.119
Rank	1	2	3

Table 13: Width of HAZ Response Table for Mean

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	1.691	1.760	1.967
2	1.981	1.980	2.059
3	2.330	2.262	1.977
Delta	0.639	0.502	0.092
Rank	1	2	3

Table 14: Width of HAZ Response Table for S/N Ratio

Level	A (Current)	B (Arc Length)	C (Welding Speed)
1	3.967	4.250	5.206
2	5.465	5.389	5.645
3	6.777	6.570	5.358
Delta	2.811	2.319	0.439
Rank	1	2	3

Main effect plot to determine optimal level for the optimal parameter is shown in Figure 1, Figure 2, Figure 3, Figure 4, Figure 5, Figure 6, Figure 7 and Figure 8.

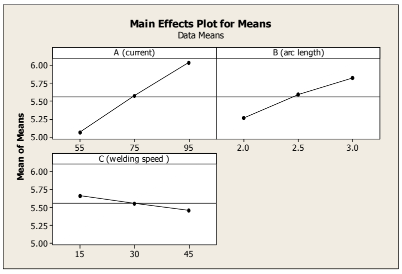

Figure 1: Main Effect Plot for Mean (BW)

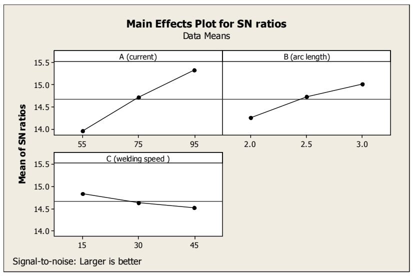

Figure 2: Main Effect Plot for S/N Ratio (BW)

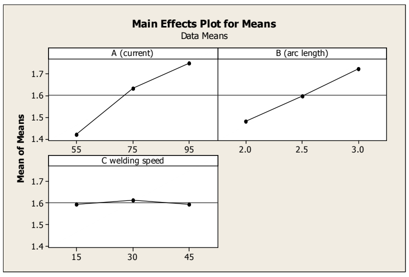

Figure 3: Main Effect Plot for S/N Mean (DP)

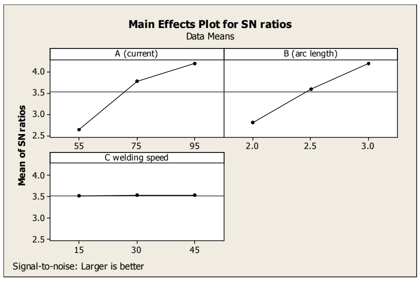

Figure 4: Main Effect Plot for S/N Ratio (DP)

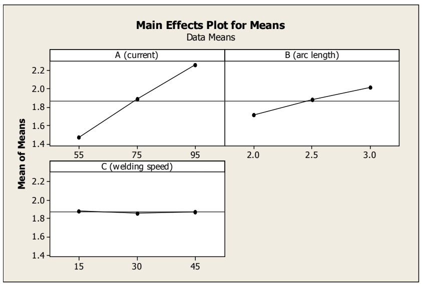

Figure 5: Main Effect Plot for Mean (Depth of HAZ)

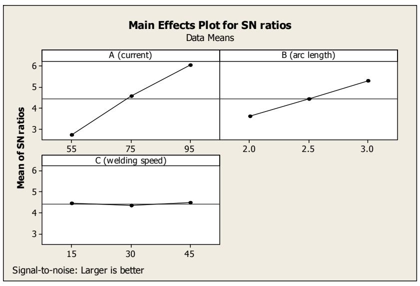

Figure 6: Main Effect Plot for S/N Ratio (Depth of HAZ)

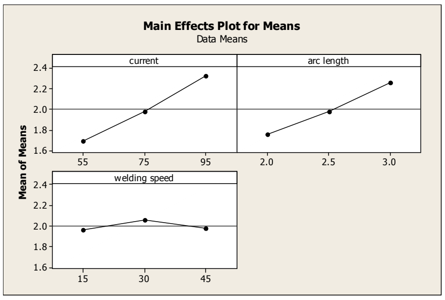

Figure 7: Main Effect Plot for Mean (Width of HAZ)

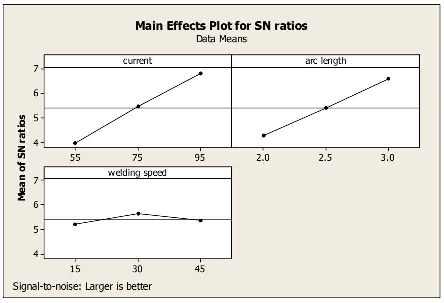

Figure 8: Main Effect Plot for S/N Ratio (Width of HAZ)

For all categories of quality performance criteria (LB or HB), the higher S/N ratio provided smaller variance of the output characteristics above the desired target. Results of ANOVA are shown in Tables 15, 16, 17 and 18. In the ANOVA tables here, degrees of freedom (DF) correspond to terms in a sum of squares (SS), which can be assigned arbitrarily. For example, the sum of deviations from the P mean in a sample of n observations:$\sum(x-x)^2$= $(x_1-x)^2 + (x_2-x)^2 + \ldots(x_n-x)^2$ has *n-1* degree of freedom, because when *n-1*deviation are known, n^{th} can be obtained from the identity $(x_1-x)^2$+ $(x_2-x)^2 + \ldots(x_n-x)^2 = 0$.

Table 15: ANOVA Results for Bead Width

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
A	2	2.86140	2.86140	1.43070	114.17	0.009	72.494
B	2	0.89954	0.89954	0.44977	35.89	0.027	22.7899
C	2	0.16110	0.16110	0.08055	6.43	0.135	4.0814
Error	2	0.02506	0.02506	0.01253			
Total	**8**	**3.94710**					

Table 16: ANOVA Results for Depth of Penetration

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
A	2	3.8976	3.8976	1.9488	53.51	0.018	56.78
B	2	2.8929	2.8929	1.4464	39.71	0.025	42.15
C	2	0.0005	0.0005	0.0002	0.01	0.994	$7.28*10^{-3}$
Error	2	0.0728	0.0728	0.0364			
Total	**8**	**6.8638**					

Table 17: ANOVA Results for Depth of HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
A	2	16.5359	16.5359	8.2679	117.68	0.008	78.78
B	2	4.2911	4.2911	2.1456	30.54	0.032	20.44
C	2	0.0219	0.0219	0.0110	0.16	0.865	0.10
Error	2	0.1405	0.1405	0.0703			
Total	**8**	**20.9894**					

Table 18: ANOVA Results for Width of HAZ

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
A	2	11.8662	11.8662	5.9331	2462.73	0.000	58.63
B	2	8.0699	8.0699	4.0350	1674.86	0.001	39.87
C	2	0.2980	0.2980	0.1490	61.86	0.016	1.47
Error	2	0.0048	0.0048	0.0024			
Total	**8**	**20.2390**					

Then $n-1$ degrees of freedom thus correspond to the $n-1$ independent comparisons, which can be made with the n observations [15]. Similar to factorial experiments, which are designed to enable comparisons to be made between the responses to the different treatment combinations, these comparisons can be associated with the degrees of freedom occurring in the analysis of variance.

$$Sum\ of\ Square\ (MS) = \frac{Sum\ of\ Square\ (SS)}{Degree\ of\ freedom\ (DF)} \quad (1)$$

F is called the variance ratio. F calculated is defined as:

$$F_{calculate} = \frac{\text{MS for any term(main or combined effect)}}{MS\ for\ error\ term} \quad (2)$$

$F_{calculated}$, thus obtained, has to be compared with F0.05and F0.01 (from standard F tables) for investigating whether the term (main effect or interactive effect) imposes a significant effect on the selected response at 95% and 99%confidence levels, respectively [17]. A factor is said to have a significant effect on a response if the tabulated F value becomes less than the calculated F value. ANOVA has been performed in the statistical software package MINITAB. It uses the P-value, termed as the probability of significance. P- value is calculated based on calculated F-value. P-value thus obtained is then compared with the Alpha-level. The presumed Alpha level depends on the confidence level chosen. If the P-value appears less than 0.05, then it can be concluded that the corresponding factor has a remarkable influence on the selected response, at 95% confidence level. In this paper interaction of factors has been neglected. If an interaction effect had been considered, then the Taguchi orthogonal array design would likely be changed, and a new experiment is to be performed. Moreover, literature depicted in the Reference list shows that in all cases the interaction effect was neglected while solving optimization problems using the Taguchi method ANOVA for the responses are shown in Tables 15, 16, 17 and 18.

CONCLUSIONS

In this study, parameter optimization has been done to find the optimal parameter. It has been found that current is the most important factor that affects the performance characteristics. The Taguchi method is very efficient for process/product optimization that can be performed in a limited number of experiments run. The main effect plot will give the optimal level for each optimal process parameter. ANOVA is used to find the % contribution of each process parameter in the performance characteristics. However, it is realized that there are no single techniques that appear to be superior in solving a different kind of problem. Integration of Taguchi method with other approaches is necessary when we have multiple responses in the performance characteristics. Taguchi method can be integrated with Numerical Simulation, Grey Relation Analysis (GRA), Principal Component Analysis (PCA), Artificial Neural Network (ANN) & Genetic Algorithm (GA).

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REFERENCES

1. *Dinesh Kumar R, Elangovan S, Siva Shanmugam N, June 2014 "Parametric optimization of Pulsed TIG Welding Process in Butt Joining of 304L Austenitic Stainless Steel Sheet" IJRET: International Journal of Research in Engineering and Technology, ISSN: 2319-1163, ISSN: 2321-7308*
2. *S Elangovan, S Venkateshwaran and K Prakasan, 2012 'International Journal of Advanced Engineering Research and Studies. Vol. I/ Issue III/April-June, E-ISSN2249–8974.*
3. *SanapDeepali, Prof. Galhe D. S, Prof. Burkul R. M, May 2015 "A Review Paper on Effect of welding speed and groove angle on strength of butt joint using TIG welding" International Journal Of Engineering Science & Research Technology ISSN:22779655*
4. *P. K. Giridharan, N. Murugan 2009 'Optimization of pulsed GTA welding process parameters for the welding of AISI 304L stainless steel sheets'The International Journal of Advanced Manufacturing TechnologyJanuary 2009, Volume 40, Issue 5–6, pp 478–489*
5. *Sunadaresan S, Janaki Ram G. D, "Use of magnetic arc oscillation for grain refinement of gas tungsten arc welds in titanium alloys". SciTechnol Weld Joining 1999;4 (3):151–60.*
6. *Kumar A, Sundarrajan S. "Selection of welding process parameters for the optimum but joint strength of an aluminum alloy". Mater Manuf Process2006;21(8):789–93.*
7. *AmitavaMitra, 2012 'Experimental Design and the Taguchi Method' Fundamentals of Quality Control and Improvement: Solutions Manual to Accompany, Third Edition. Print ISBN: 9780470256978 Online ISBN: 9780470409831*
8. *Antony J, Antony F (2001) Teaching the Taguchi method to industrial engineers. Work Study 50(4):141–149*
9. *Rowlands H, Antony J, Knowles G (2000) An application of experimental design for process optimization. The TQM Magazine 12(2):78–83*
10. *Sang-Heon L, Choon-Man L, Won Jee C (2006) A study on the optimal cutting condition of a high-speed feeding type laser cutting machine by using Taguchi method. Int J PrecisEngManuf 7(1):18–23*
11. *Unal R, Dean Edwin B (1991) Taguchi approach to design optimization for quality and cost: an overview. Presented at the 13th annual conference of the international society of parametric analysis, New Orleans, LA, 21–24 May*
12. *Yang WH, Tarng YS (1998) Design optimization of cutting parameters for turning operations based on the Taguchi method. J Mater Process Technol 84:122–129*
13. *Nalbant M, Gökkaya H, Sur G (2006) Application of Taguchi method in the optimization of cutting parameters for surface roughness in turning. Mater Des (in press)*
14. *Yang WH, Tarng YS (1998) Design optimization of cutting parameters for turning operations based on the Taguchi method. J Mater Process Technol 84:122–129*
15. *V. Modanloo, R. Hasanzadeh, P. Esmaili, The Study of Deep Drawing of Brass-steel Laminated Sheet Composite Using Taguchi Method, International Journal of Engineering (IJE), TRANSACTIONS A: Basics. Vol. 29, No. 1, (January 2016) 103-108*
16. *Davis OL (1978) Design and analysis of industrial experiments. Longman, New York*
17. *Minitab, Inc. (2000) MINITAB release 13.1, user's manual. Minitab, Inc., State College, PA, U*